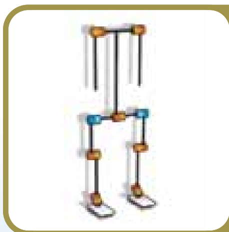
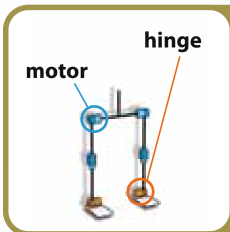
Wobbly walker evolves into

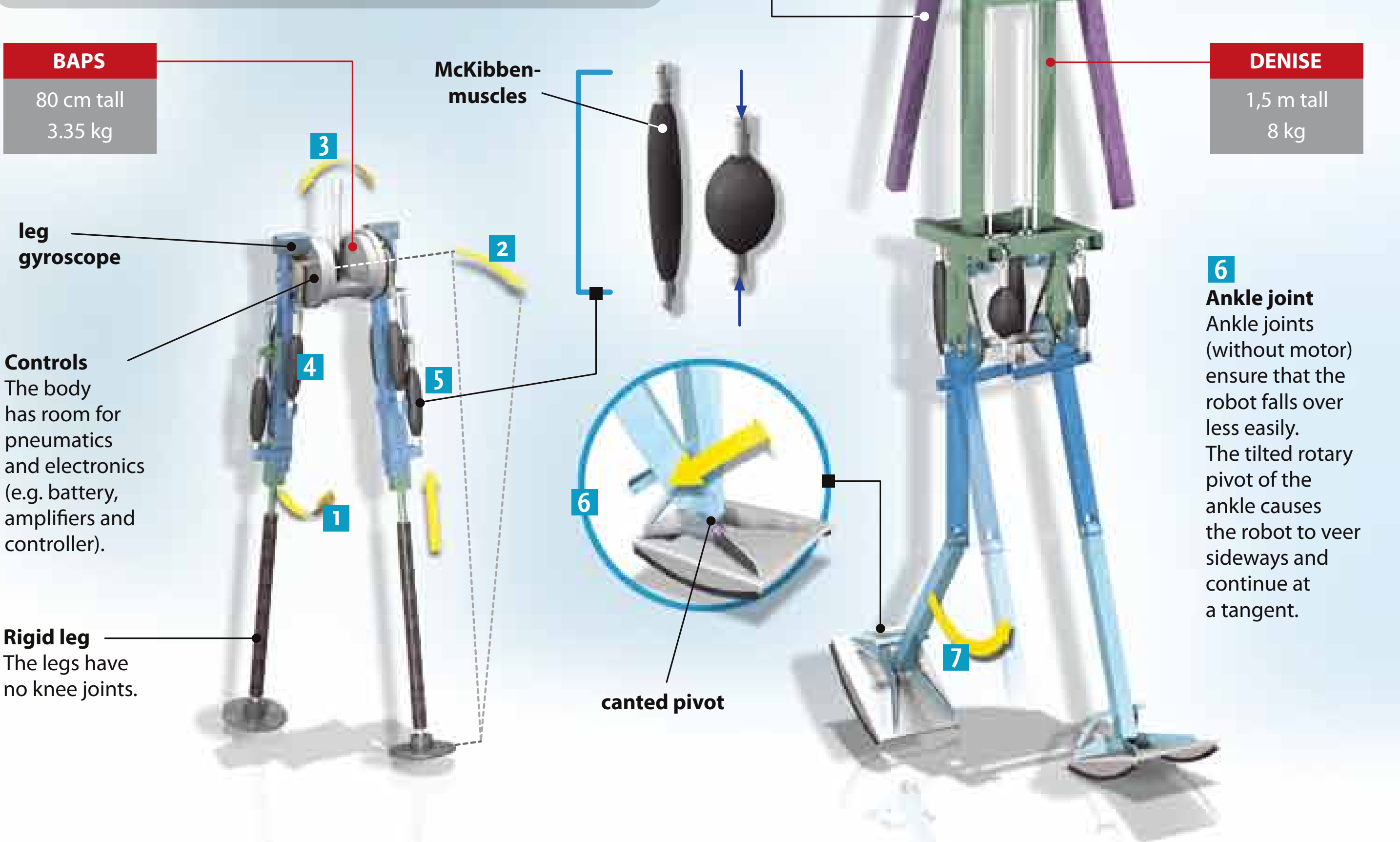
Seventeen years ago, a graduate student of the Faculty of Mechanical, Maritime and Materials Engineering built the first Delft walking robot. Not a walking computer with heavy motors, but an energy-efficient autonomous robot. That quest into human walking has developed into the Delft Biorobotics Laboratory, where 15 researchers work on biologically inspired robots. New insights should contribute towards the treatment of people with walking disabilities. Whereas the first robot, Baps, could take a few steps, the latest robot, TUlip, must be able to play a bit of football. This infographic sets out the evolution of four walking robots developed as PhD projects. More information: **www.dbl.tudelft.nl**.



Passive dynamic walking
The objective was to create a robot that passively performs a natural, stable walking motion, without a controlling device. Motion instability is self-correcting.



Coupled cyclic motion
The objective was to create a light, energy-efficient bipedal walking robot. Stability had to occur automatically by harmonising the natural oscillatory motions of swing leg 1, body 2 and lateral motion 3.



Pneumatic muscles
The robot is actuated by six pneumatic artificial muscles. The muscles consist of rubber balloons in plastic sheaths. Increase in pressure causes the muscle to contract; the sheath cannot extend, only expand in diameter. A simple controller activates the hip muscle 4 of the swing leg, based on the signal of a gyroscope. The hip muscle contracts and propels the leg forward. Simultaneously, another muscle 5 extends the stand leg, enabling the swing leg to make its swing (to prevent it dragging the ground).

Result RICHARD VAN DER LINDE, DOCTORATE 2001

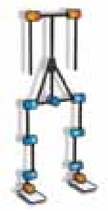
The walking motion does not automatically lead to lateral stability. The robot takes up to eleven steps and then falls.

Knee hinges
Knee joints make the walking motion more humanlike (the knees = Denise). The knee joint has no motor and therefore uses no energy. There is, however, a controllable latch. When the left foot lands on the ground, a sensor under the foot sends a signal to the right knee to be released. At the same time, the hip muscle ensures that the right leg swings forward. Because inertial mass holds the foot back, the knee bends during the swing 7. At the end of the swing, the right leg is straightened again and the knee becomes locked. The rigid leg now becomes the stand leg and the movement is repeated.

Result MARTIJN WISSE, DOCTORATE 2004

Denise takes 20 steps before falling. She is unable to start walking from a standstill position; she must first be set in motion.

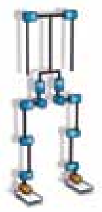
soccer star



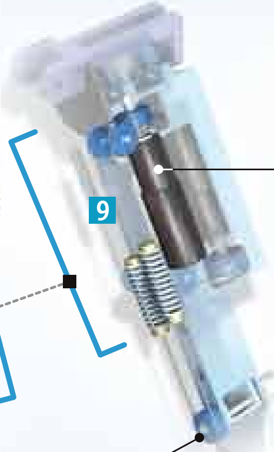
Convergence towards walking stability
The objective was to measure disturbances (with balance sensors in the body) so that the walking motion can automatically be recovered. In order to achieve this, the robot has motors in its ankles and knees. During a disturbance, the robot moves its feet sideways to retain upright stability.

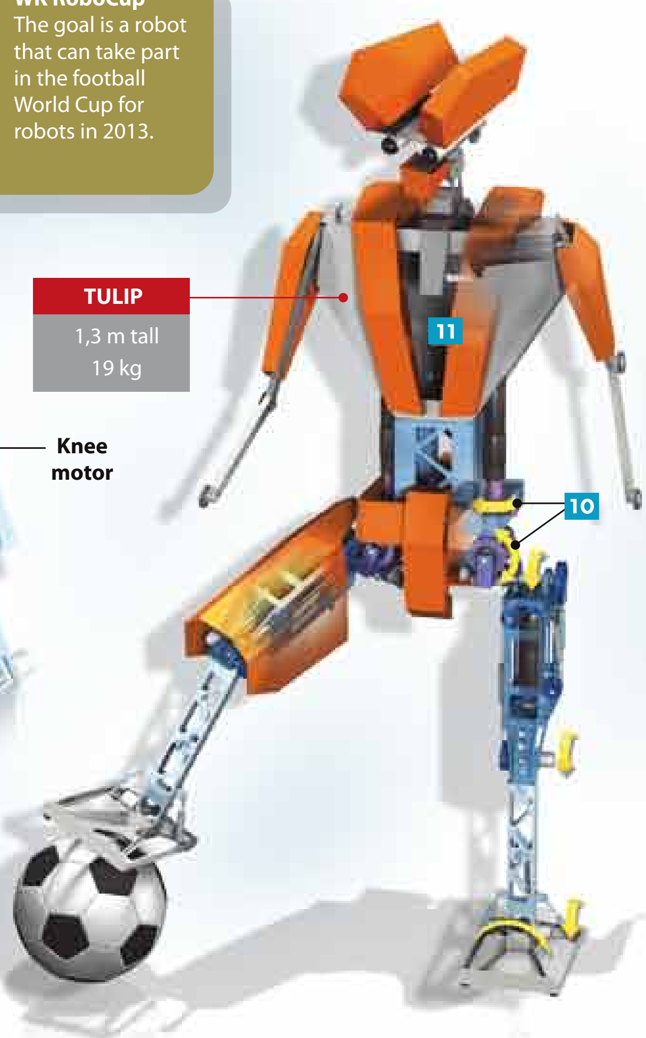
Ballistic walking

The most elementary bipedal robot, hips with rigid legs, can walk unaided down a slope. The robot remains standing on one leg (the stand leg) while the body tips forward. At the same time, the other leg (swing leg) swings forward (humans would bend their knee), the foot comes down on the ground and takes over the function of the stand leg. The natural pendular motion of the legs makes walking very energy-efficient. This ballistic approach by the Delft Biorobotics Lab is quite different to the approach to the Japanese Asimo, where each movement is controlled and stopped by heavy motors that use a lot of energy.



WK RoboCup
The goal is a robot that can take part in the football World Cup for robots in 2013.





Flame head
Flame has TU Delft's flame logo as a head.

FLAME
1,3 m tall
15 kg

ankle motor

8 Body motor
The sideways movements of the legs are coupled by means of a spindle motor. This single motor keeps the body automatically upright.

TULIP
1,3 m tall
19 kg

Electric elastic motors
In order to walk smoothly, the coupling that actuates the joints must be continually adjustable. This is difficult to achieve with pneumatic muscles. Flame is therefore equipped with seven electric motors. Each motor spindle is connected to a joint by a cable 9 and two springs. The motor and the joint contain angular displacement encoders. By measuring the variation in angular displacement (3000 counts per revolution), the extension of the spring (and therefore the joint's torque) is known. This makes torque control possible, necessary for smooth walking.

Result DAAN HOBBELEN, DOCTORATE 2008

Flame can walk thirty steps straight ahead and step over 8 mm bumps. Flame loses her balance and falls over when nudged.

Optimum place to put your feet
If a robot stands on one leg and starts to fall, it can regain its balance by placing its other foot on the ground. In this research project the optimum place where the robot should put its foot was calculated (= capture point theory). To make it possible for the robot to place its foot anywhere, both legs have complete freedom of movement (six degrees of freedom). This requires two extra motors 10 for each leg.

Body 11
The body is filled with electronics, batteries and a control system.

Result TOMAS DE BOER, DOCTORATE 2012

Tulip can balance on a wobbly plank and remain upright when nudged (can be viewed on youtube). Stable walking requires further research.